Carbon Dioxide, Coral Reefs and Climate Change

Two biological processes drive the carbon cycle on coral reefs: 1) Organic carbon metabolism (photosynthetic fixation and respiration) and 2) Inorganic carbon metabolism (precipitation and dissolution of calcium carbonate). The simplified equations for these processes are listed below.

Organic carbon metabolism

Photosynthesis

$$CO_2 + H_2O \rightarrow CH_2O + O_2 \quad (1)$$

Respiration

$$CH_2O + O_2 \rightarrow CO_2 + H_2O \quad (2)$$

Inorganic Carbon metabolism

Calcification

$$2HCO_3^- + Ca^{2+} \leftrightarrow CaCO_3 + CO_2 + H_2O \quad (3)$$

Dissolution of carbonate

$$CaCO_3 + CO_2 + H_2O \leftrightarrow 2HCO_3^- + Ca^{2+} \quad (4)$$

Carbon dioxide (CO_2) concentrations, a greenhouse gas found in the Earth's atmosphere, have increased since pre-industrial times primarily due to the combustion of fossil fuels. Based on realistic scenarios of future emissions this trend will continue and atmospheric CO_2 concentrations are expected to reach double pre-industrial levels by 2065 (Houghton et al. 1996). Elevations in atmospheric CO_2 are predicted to cause an increase in the partial pressure of CO_2 (PCO_2) in the surface ocean, thus causing seawater to become more acidic (Broecker et al. 1979). The rationale behind this is due to the fact atmospheric CO_2 is in equilibrium with CO_2 in the oceans, thus any increase in atmospheric CO_2 will result in an increase in seawater CO_2. The reactions for this process are given below.

$$CO_2\ (gas) \leftrightarrow CO_2\ (aqueous)$$

$$CO_2\ (aqueous) + H_2O \leftrightarrow H_2CO_3\ (carbonic\ acid)$$

$$H_2CO_3 \leftrightarrow H^+ + HCO_3^-\ (bicarbonate)$$

$$HCO_3^- \leftrightarrow H^+ + CO_3^{2-}\ (carbonate)$$

The interaction of CO_2 in seawater with calcium carbonate ($CO_2 + H_2O + CaCO_3 \leftrightarrow 2HCO_3^- + Ca^{2+}$) shows how an addition of CO_2 enhances $CaCO_3$ dissolution and removal of CO_2 enhances its precipitation. For example, the addition of more CO_2 on the left side of the equation pushes the reaction to the right favoring dissolotion of $CaCO_3$ to balance the reaction, and vice versa. Based on these assumptions laboratory studies have shown that a doubling in the concentrations of CO_2 (aqueous) can cause a 20-54% reduction in the calcification of corals (Langdon et al. 2000; Leclercq et al. 2000; Leclercq et al. 2002; Langdon et al. 2003).

Specific concern is raised in regards to the persistence of reef structures as carbonate budget studies have demonstrated that constructive (calcification) and destructive (bioerosion, mechanical erosion) processes are closely balanced on many reefs with net reef accumulation barely ahead of net reef loss (Scoffin et al. 1980; Glynn 1988). Thus, even small-scale shifts reducing coral calcification associated with increases in CO_2 concentrations may result in net reef loss.

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